DIELECTRIC CONSTANT AND POWER FACTOR MEASUREMENTS OF ICE

BY
VICTOR ANTHONY YARBOROUGH
A.B., Sioux Falls College, 1939

AN ABSTRACT OF A THESIS
SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN
CHEMISTRY IN THE GRADUATE SCHOOL OF
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DIELECTRIC CONSTANT AND POWER FACTOR MEASUREMENTS OF ICE

Introduction

Some molecules contain permanent rigid dipoles whose moment is independent of, but which tend to orient with, the applied external field. Debye[1] has developed equations for the dielectric constant of such molecules. Debye's complex dielectric constant is composed of two parts, one real and the other imaginary. Accordingly $\epsilon = \epsilon' - i\,\epsilon''$. ϵ', the out of phase component, is what is usually referred to as the dielectric constant. ϵ'', the in phase component, represents the leakage or dielectric loss. Such a representation corresponds to a branched circuit containing resistance and capacity. ϵ' and ϵ'' must vary with frequency since they represent the conductance and susceptance of such a parallel circuit.

The differential equation of motion for a rotating dipole which is subjected to an alternating force is mathematically equivalent to the differential equation for an electrical circuit containing inductance, resistance, and capacity in series. Consequently one must take this into account by having all those variables in the electrical circuit or by calculating them from balance conditions of a simpler circuit.

Discussion of Results

Dielectric constant and power factor measurements were taken on naphthalene, ice, and solid anhydrous hydrogen chloride. An alternating current bridge was used with a condenser and series resistance in the arm of the bridge across from the unknown. This simpler circuit was used to make for ease of obtaining an accurate balance. However, the principle of electrical equivalence says that any combination of resistance and reactance in one arm of the bridge may be balanced by some combination of resistance and reactance in the other arm, but it is by no means necessary that the arrangement be the same. The theoretical impedance may then be equated to

the actual impedance at the null point and the unknown constants ascertained.

TABLE I. DIELECTRIC CONSTANTS

Frequency cycles/sec.	Naphthalene	Ice: -20± .1°C.			Solid anhydrous HCL	
		Cell 2	Cell 3	Cell 4	ca -130°C.	ca -183°C.
200	3.56	68.15	72.50	84.68	18.65	6.80
500	3.18	64.66	66.90	75.62		
1000	3.23	53.39	53.81	56.51	17.02	6.19
2000	3.18	30.86	30.52	30.52	16.79	6.13
5000	3.28	9.67	10.49	10.68		
10000		3.93	4.75	5.32	15.96	6.12
16000		3.36		3.58		

TABLE II. RESISTANCE** OHMS

	Ice—Cell three: -20± .1°C.		Solid anhydrous HCL ca -130°C.	
Frequency cycles/sec.	series	Calculated parallel	Series	Calculated parallel
200	182000	54.224 x 10^6	7000	9.468 x 10^{10}
500	115500	16.116		
1000	75960	9.479	700	3.787
2000	33750	16.447	270	2.455
5000	5690	132.212		
10000	1970	465.498	20	0.754

**The measured series resistance of naphthalene and solid anhydrous HCL at the temperature of liquid air was negligible.

TABLE III. POWER FACTOR*

Frequency cycles/sec.	Ice -20± .1°C.		
	Cell 2	Cell 3	Cell 4
200	10.375 x 10^{-2}	5.794 x 10^{-2}	3.518 x 10^{-2}
500	17.699	8.432	4.902
1000	20.360	8.952	4.516
2000	10.156	4.530	2.024
5000	1.362	0.656	0.350
10000	0.330	0.206	0.104
16000	0.121		0.054

Ice—cell three		Solid anhydrous HCL
-25°C.	-30°C.	ca -130°C.
6.93×10^{-2}	10.17×10^{-2}	2.719×10^{-4}
9.387	7.844	
5.321	2.516	1.359
1.553	0.639	1.049
0.258	0.138	
0.098	0.062	0.388
0.028	0.021	

*The power factor of naphthalene and solid anhydrous HCL at liquid air temperatures was negligible.

Naphthalene exhibited a constant capacitance and very slight power factor throughout the audio frequency range studied (200 to 16,000 cycles per second). Since it possesses no dipole moment and has a very low conductivity, this seems to be a reasonable phenomenon.

Solid anhydrous hydrogen chloride, measured at -130°C., exhibited a constant capacitance and only a slight increase in power factor as the frequency shifted from high to low values. However, at liquid air temperatures the capacitance dropped to about one-third of its value at -130°C., then remained constant over the entire frequency range investigated. This drop in the dielectric constant is very probably due to the dipoles being fixed in position in the crystal lattice at these very low temperatures. Hence we would expect an appreciable drop in the dielectric constant and almost a disappearance of any power factor. These results would seem to indicate that the frequencies used were too low for the Debye maximum in ϵ'' and decrease in ϵ' to show up; this maximum in ϵ'' and decrease in ϵ' being characteristic of the natural frequency. At this lower temperature, the power factor was found to approach zero.

As Smyth and Hitchcock[2] also found to be the case, ice did show a maximum in ϵ'' and a decrease in ϵ', but at very low frequencies (below one kilocycle per second). Such effects due to dipole orientation might be expected but at much higher frequencies. Consequently it was postulated that the entire

crystal lattice of ice tended to be distorted by the external field and that the inductance and inductive resistance developed as a result of a lag in this distortion resulted in the rise of ϵ' and a passage of ϵ'' through a maximum as frequencies of less than one kilocycle were approached. Ice was postulated as being equivalent to a capacitance, inductance, and resistance, all in series and all shunted by a small constant capacitance. The impedance of such a theoretical circuit was equated to the measured impedance at the null point and the various known factors subsequently calculated. The expected constancy of values was not obtained indicating that ice must be even more complex in its electrical behavior than was postulated. It should be emphasized that the complex electrical behavior of ice is probably due to the presence of several natural frequencies rather than of just one as is the case for most materials with dipole moments. If the correct theoretical impedance could be found, the electrical constants should be independent of frequency. In any case, even though the mathematics involved might become rather cumbersome, it is a more practical method than to endeavor to include all possible components in the actual bridge circuit and then balance each out separately.

References

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2. Smyth and Hitchcock, J. Am. Chem. Soc., **54**, 4631 (1932).

VITA

The author was born in Sioux Falls, South Dakota on April 16, 1917. He received his elementary education in rural schools and was graduated from Hartford High School in June, 1935. He attended Sioux Falls College at Sioux Falls from 1935 to 1939, and received the Bachelor of Arts degree, summa cum laude, in June, 1939. The author attended the University of Illinois from 1939 to 1943, holding a teaching assistantship those four years while doing graduate work in Chemistry. He is a member of Phi Lambda Upsilon, Pi Mu Epsilon, and Sigma Xi.

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